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Inclusive (n,xn) Double-Differential Cross-Section Measurement (II)

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Calculating radiation transport with protons and neutrons requires a description of nucleon-induced reactions. These processes are especially important for incident energies above 20 MeV for the development of accelerator-driven systems (ADSs). The quantity that describes the probability of a nucleon being emitted at a given angle with a given energy is called the double-differential cross section (DDX). For proton-induced reactions, DDXs have been measured for many years. But DDX data for neutron-induced reactions where neutrons are emitted have never been obtained above 100 MeV. This article describes the measurements that we obtained at WNR of inclusive (n,xn) cross sections (i.e., one neutron is detected, but no other reaction product *x*) for incident-neutron energies ranging from 20 to 400 MeV. These cross sections will be compared to calculations from the intra-nuclear-cascade-evaporation (INCE) code,[1] the quantum-molecular-dynamics (QMD) code,[2] and the GNASH code.[3]

DDX Data — Needs and Challenges

Intermediate-energy proton accelerators are used in conceptual ADSs. To design these facilities, DDX measurements of proton-induced reactions were performed after 1988. These data contributed to improvements to the INCE, QMD, and GNASH codes.[1-3] For instance, predictions from recent INCE calculations have greatly improved since the early 1970s. Adjustments to parameters, such as the effective nucleon-nucleon-collision cross sections at medium energies, were made in INCE and QMD codes.

The present state of data suggests that the nuclear-model codes might have trouble predicting DDXs. For example, it is well known that there are relatively important changes in the nuclear-optical potential[4] in the 50- to 300-MeV energy region. The optical-model parameters are important input to the calculations. Secondly, DDX data for proton-induced reactions barely cover this energy range, and therefore they do not constrain the calculations as much as needed. Then there are the thick-target-neutron yields[5] that we measured for incident-proton energies around 1 GeV; these have some disagreement with the results of the LAHET code[6] in the energy region of 20 to 100 MeV. Thus, even proton-induced data leave much to be desired in the development of reaction-model codes to predict neutron-induced DDXs.

Measurement of (n,xn) Cross Sections

WNR provides short, intense neutron pulses over a wide continuous-energy range that covers the nuclear-optical-potential changing region. Data at these energies can supplement those for proton-induced reactions for improving the INCE model and thus provide advances in intermediate-energy nuclear physics and neutron-transport calculations.

The purpose of our study was to measure inclusive Fe(n,xn) and Pb(n,xn) DDXs for incident neutrons with energies from 20 to 400 MeV. The measurement required an experimental method that had both an acceptable detection efficiency and a good energy resolution.

The experiment shown in Fig. 1 was performed on WNR flight path 4FP15L. With a continuous-energy-neutron beam, the time between neutron production from the spallation target and the detector signal gives the sum of the flight times for the incident and emitted neutrons. The time of flight (TOF) of emitted neutrons can be obtained from their energy measured in the detector. The TOF of incident neutrons is obtained by difference. To detect the emitted neutrons, we used the recoil-proton method in 2001.[7] However, the detection efficiency of the method was very low. To improve the efficiency, we used liquid-organic scintillators as neutron detectors and the recoil-proton method in 2002.

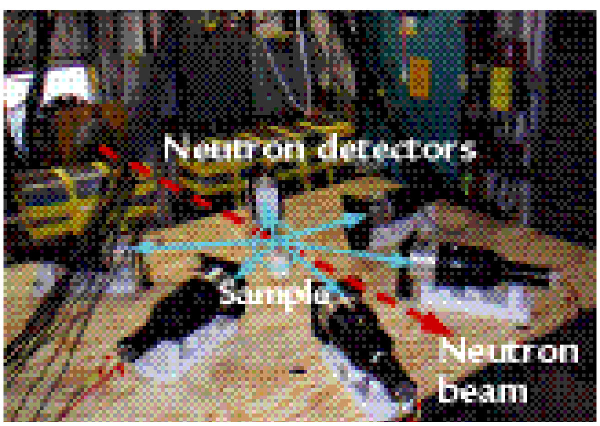

Fig. 1. Detector arrangement showing the direction of the incident neutron beam, the Pb sample, and the liquid-organic-scintillation detectors.

The distance between the sample and the liquid-organic-scintillation detectors was about 50 cm, and the detection angles were 15°, 30°, 60°, 90°, 120°, and 150°. The samples used were a 4-cm-thick, 5-cm-diam Fe disk and a 2-cm-thick, 5-cm-diam Pb disk. To subtract background events, we also made measurements without the samples. To eliminate charged-particle events from the sample, a plastic scintillator was set in front of each scintillation detector.

Conclusion

The data obtained at WNR cover the neutron energies from 20 to 400 MeV. Data analysis is in progress.

References

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